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Lewis Research Center
21000 Brookpark Road
Cleveland, Ohio 44135

Lewis Research Center Space Station Electric Power System Test Facilities

April 28, 1988

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Space Station Systems Directorate
Work Package 04 (WP-04)
Space Station Electric Power System

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**SPACE STATION SYSTEMS DIRECTORATE
ELECTRIC POWER SYSTEM TEST FACILITIES
APRIL 28, 1988**

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SPACE STATION SYSTEMS DIRECTORATE
ELECTRIC POWER SYSTEM TEST FACILITIES

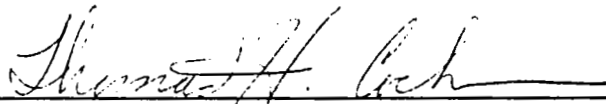
APRIL 28, 1988

APPROVED BY:



WILLIAM E. GOETTE
CHIEF, OPERATIONS DIVISION

CONCURRENCE BY;



RONALD L. THOMAS
DIRECTOR, SPACE STATION SYSTEMS DIRECTORATE

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1.0 INTRODUCTION

The Space Station is a low Earth orbit facility that will operate with complementary interfacing space systems to support various manned and unmanned space operations beginning in the 1990's and continuing for approximately thirty years. While specific missions have not been scheduled into the Space Station, the nature of the missions to be performed is known. The current "design" of the Space Station is an engineering reflection of these mission requirements.

The Space Station System is a combination of manned and unmanned spacecraft which will evolve and grow over time. The manned spacecraft, the Space Station, will provide for onboard research, technology, and commercial activities requiring man's presence, for assembly and construction of large systems, and operational support to companion free flying satellites and platforms. The unmanned platforms, will be operated in both relative proximity (co-orbiting) and in polar orbits and will provide a highly controlled environment for certain scientific missions.

Because of the size of the Space Station, and the nature of its mission, design criteria different from those of previous programs must be met. These considerations are reflected in the Space Station electric power system in several ways. The power system must support station activities which will change as activities on the station evolve. The power system must be flexible enough to meet changing demands and growth over the thirty year station life. Initial power demands are expected to grow as station usage increases. The power system must be modular with well defined interfaces to accommodate repair by replacement and growth without disruption. It should also be able to accept new technology as it becomes available or as it is needed. The power system consists of a photovoltaic (PV) generation system, and a power management and distribution system (PMAD). The Phase 2 configuration adds a solar dynamic (SD) generation system. NASA's Lewis Research Center WP-04 has been charged with responsibility for design, development, fabrication, test, verification, and delivery of the electric power system that will be incorporated into the manned Space Station and providing common hardware and software for the platforms.

The basic objective of the electric power system test program is to demonstrate the performance and system compatibility of the Space Station electric power system. The testing shall consist of highly structured tests using specified and controlled stimuli. The certified data produced should adequately demonstrate the success of the test in achieving the specified performance criteria.

The Lewis Research Center (LeRC) Phase C/D Contractor is authorized to use LeRC facilities in the performance of his contract. In addition, requests for the use of the LeRC facilities may be received from the other work packages. It is the intent of this document to describe certain facilities available at LeRC and to provide other information that will set the responsibilities for the Contractor and NASA regarding the use of the facilities.

2.0 ELECTRIC POWER SYSTEM FACILITIES REQUIRED FOR WP-04 PHASE C/D CONTRACTOR USE

The Phase C/D RFP specifies three LeRC facilities to be used in the contract effort. The facilities are the Power Systems Facility (PSF), the Space Power Facility (SPF), and the EPS Simulation Lab (EPSSL). Two facilities are new for the project (PSF, EPSSL) and one is currently being renovated (SPF).

2.1 POWER SYSTEMS FACILITY

The Power Systems Facility (PSF) (Figs. 2.1.1, 2.1.2) is a FY87 CoF project and is currently under construction. It is expected to be operational in April 1989. Construction began in March 1987 and will be finished in November 1988 with preliminary outfitting to begin in August of that year. The facility is located in the West area of the Lewis Research Center (LeRC) adjacent to the currently operational solar array field.

The facility, Building 333, has been provided with air conditioning in most areas and heating and ventilation in all other areas, 400 kW of process cooling water, 300 KVA of electrical power, and 3 pounds per second (125 psi) of service air.

The main test area is "L" shaped area of 8300 sq. ft., with a clear height of 55 feet and a 10 ton crane. Primary access into the main test area is through an air shower. A loading/unloading area with its own 10 ton crane and workshop is adjacent, with access through a 16 ft. high telescoping door.

Individual test cells are provided for power processing components, energy storage (Ni-H₂ batteries), power source simulators, loads, and solar dynamic subsystems. These areas are served by air conditioning, ventilation, service air, and process cooling water. Reinforced concrete blast walls, and blow-out panels in the exterior walls are provided in the load and energy storage test cells. The power processing test cell has a depressed floor slab with a computer access floor system.

A Control Room, Computer Room, and Controls/Data Lab will be provided to support the main test area and test cells. These spaces have a depressed floor slab to accommodate a computer access floor system. An Uninterrupted Power Supply (UPS) will provide noise isolation and data integrity for the computer system. Windows are facing the test area in order to monitor testing.

The building also contains an Entry Lobby, Observation/Conference Room, restrooms, offices, shop areas, employee locker rooms, and mechanical/electrical equipment rooms.

Future plans include the upgrading of the main test area to a class 100,000 clean room by adding filters and wall panels.

PSF will be equipped for testing electrical models of the Space Station Power System. Additional capability will permit testing such as development and verification of components and subsystems that are candidates for the power system and optical characterization of Solar Dynamic concentrator. Specifically, PSF contains:

1. A 30kW (peak) solar array field and solar array simulator power supplies.
2. Test cells to test Ni-H₂ cells and batteries.
3. Power loads for component and integrated system testing.
4. Energy storage (battery) simulators.
5. Computerized control and steady state data acquisition system.
6. Dynamic data system.

A proposed FY90 CoF project will provide an addition to the Power Systems Facility. The addition will support LeRC's Space Operations Support responsibilities in the Space Station program in the following areas:

1. Provide an Engineering Support Center (ESC) for the operations support, data processing, and data archiving. The ESC will utilize hardware and software simulations of the Electrical Power System.
2. Provide a Communications Center to serve as the LeRC/SSIS interface and provide local distribution of Space Station and Platform data/voice/video.

Additional outfitting and additional support equipment will be determined by the Government after negotiation of the Phase C/D contract.

2.2 SPACE POWER FACILITY

The Space Power Facility (SPF), located at the LeRC Plum Brook Station near Sandusky, Ohio, is currently undergoing restoration. The facility (Figs. 2.2.1, 2.2.2) will be operational when the restoration is completed in late 1988. An interface document will document the facility status at that time.

A 1991 CoF project has also been proposed for SPF. The facility with expanded capabilities would be operational in 1993. The CoF project is based on a Preliminary Engineering Review (PER) which was completed in mid-July, 1987.

The facility, Building 1411, contains a 100 ft. diameter by 121 ft. high vacuum chamber with the highest point being the top of the hemispherical roof. 8,000 GPM of process cooling water, 15,000 KVA of electrical power, and 850 SCFM of natural gas are available. The building is made up of an assembly area, a disassembly area, and a test chamber. The assembly area is 75 ft. wide by 150 ft. long with a clear height of 80 ft. The assembly area is equipped with a 25-ton capacity overhead bridge crane and three sets of parallel railroad tracks which extend into the test area. The disassembly area provides a space 70 ft. wide by 150 ft. long with a clear height of 76 ft. The disassembly area is provided with a remotely-controlled overhead bridge crane. This equipment is operated from exterior galleries provided with viewing windows. Railroad spurs are provided to both the assembly and disassembly areas of the building.

The test chamber provides the capability to conduct environmental testing in a high vacuum and at cryogenic temperatures. The chamber is constructed of 5083 aluminum which is clad on the interior surface with 1/8 inch thick 3003 aluminum for corrosion resistance. The doors on the test chamber are curved to fit the cylindrical shape of the chamber. The two entrances are 50 ft. by 50 ft. in size and are 180 degrees apart. Other features of the test chamber include an 8 ft. by 8 ft. air lock, a full complement of service penetrations, and a floor rating of 200 tons.

SPF also has 20,000 sq. ft. of offices: control rooms, change rooms, and equipment rooms. The control room provides a focal point for test operations. Functions such as overall control and monitoring of tests, safety monitoring, and emergency control are provided.

SPF is required to support system validation of the PV power module and will be utilized for SD module validation. Some of its planned capabilities include:

1. Vacuum simulation – To simulate LEO conditions for the Space Station power system tests, it will be capable of operating in the 10^{-6} torr range. Vacuum capability to be available late 1988.
2. Thermal simulation – The 1991 CoF modifications will provide a cold wall system capable of handling a cold wall load of 800kW. The preliminary design concept provides for a cold wall 96 ft. in diameter and 74 ft. high with flat sides in the door area with a shroud 82 ft. across in this area. Twenty-two control zones are planned. A 40 ft. dia. by 40 ft. high cold wall exists and could be made operational in 1989 if a requirement exists.
3. Clean areas – the assembly and test area shall be equivalent to a class 100,000 area.

Additional outfitting and additional support equipment will be determined by the government after negotiation of the Phase C/D contract.

2.3 EPS SIMULATION LAB

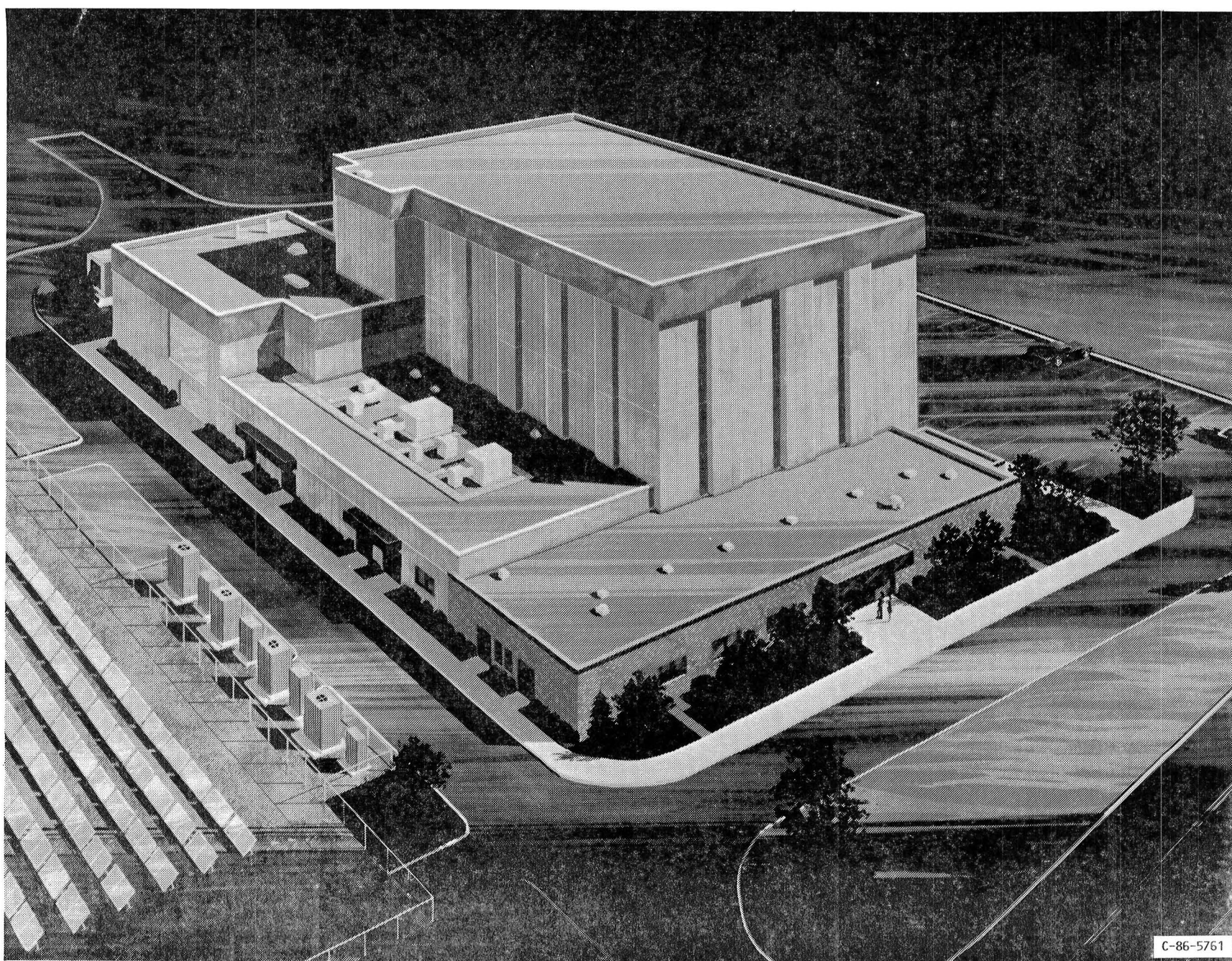
The EPS Simulation Lab (EPSSL) (Figs. 2.3.1, 2.3.2) is currently operational. The facility is located at LeRC.

The facility occupies 1,700 sq. ft. of floor space of Building 77. The ambient temperature and humidity are maintained within the limits required by the computing equipment.

Future plans include the installation of an uninterrupted power supply (UPS). The UPS will insure noise isolation and data protection for the facility.

EPSSL is intended to develop software to support the testing and evaluation of components and systems involved in the Space Station Electric Power System. This software includes power system control algorithms and power system simulation for the PV, SD, and hybrid configuration. It also can be used in evaluating the ADA software language for real-time power system control algorithms. The facility includes the following hardware/software.

1. VAX 11/780
2. Six VAX terminals
3. Real-time simulation processor
4. Apollo workstation
5. Intel microprocessor development
6. Softech ADA Language System
7. DEC ADA Compiler

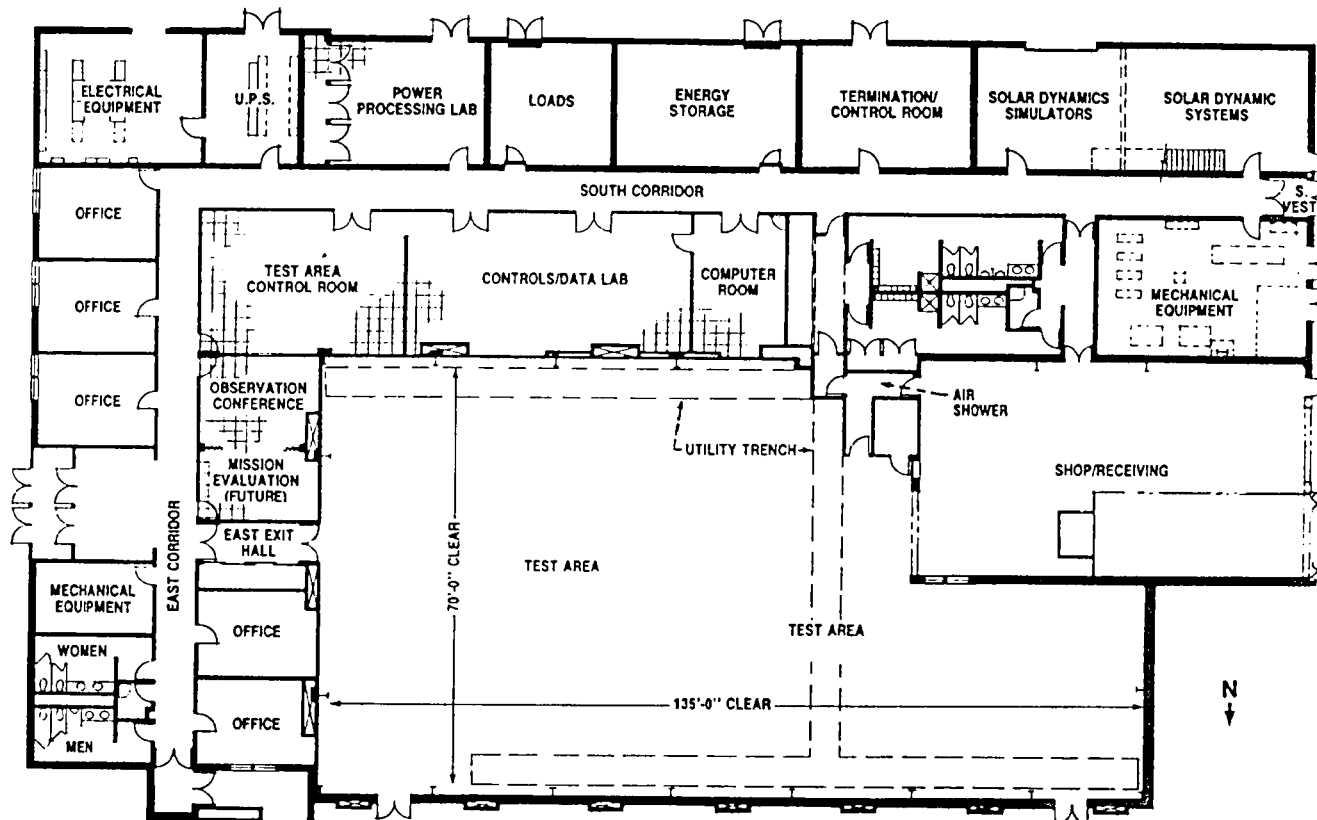


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FIGURE 2.1.1. - POWER SYSTEMS FACILITY.

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LEWIS RESEARCH CENTER POWER SYSTEMS FACILITY



FLOOR PLAN

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FIGURE 2.1.2. - POWER SYSTEMS FACILITY FLOOR PLAN.

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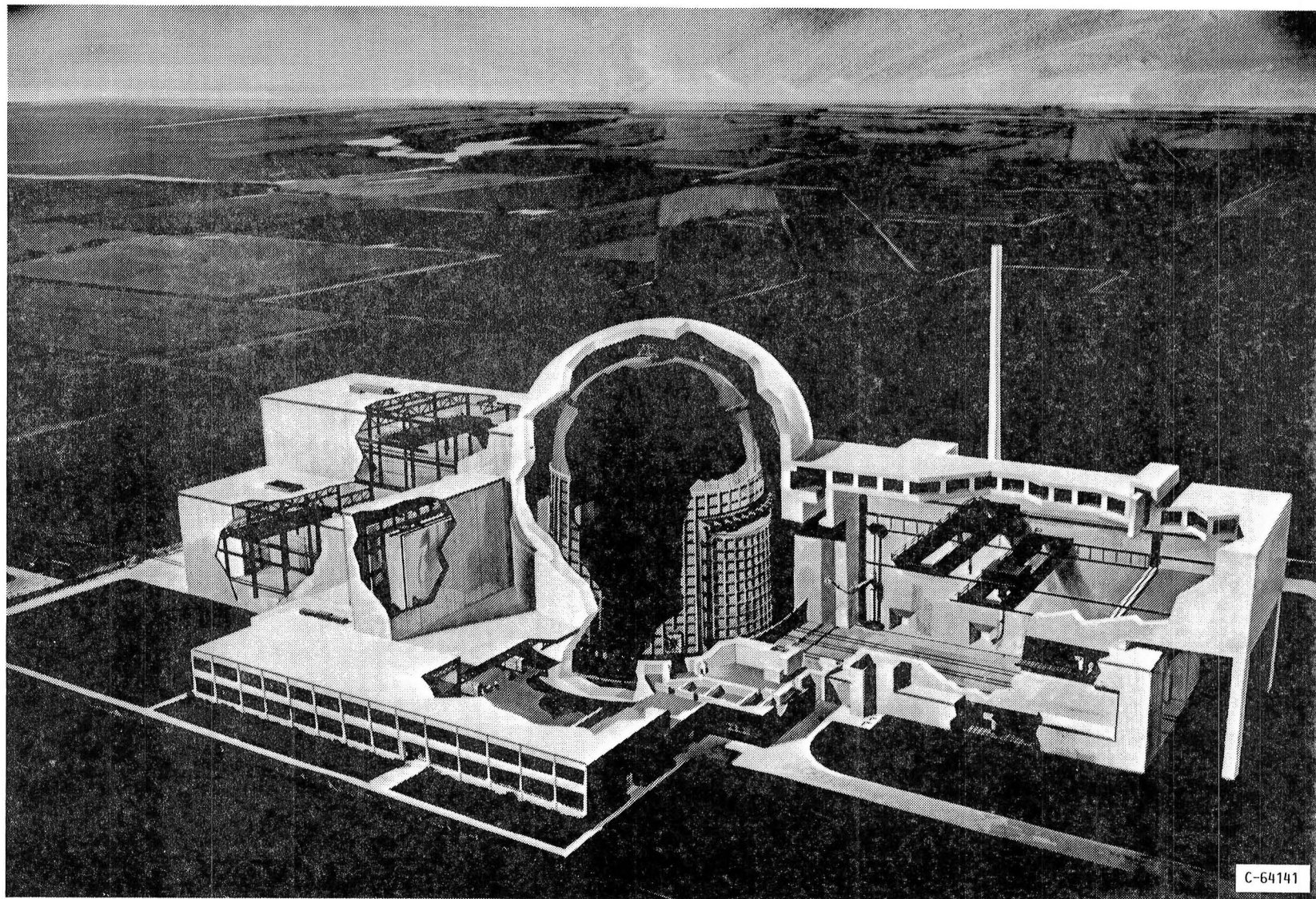


FIGURE 2.2.1. - SPACE POWER FACILITY.

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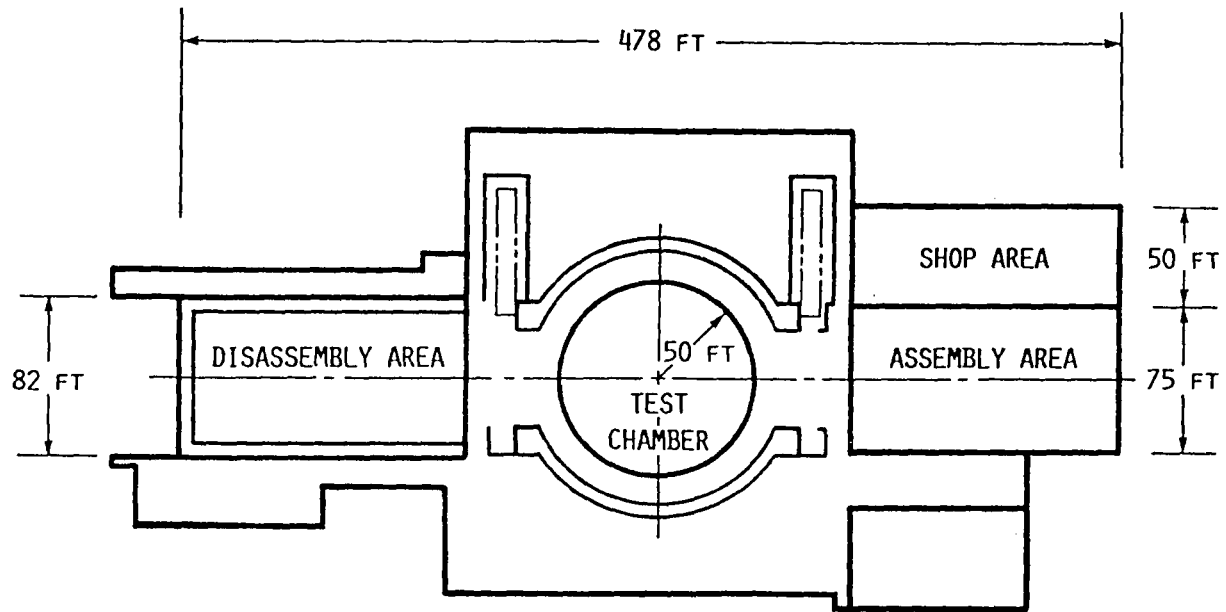


FIGURE 2.2.2. - SPACE POWER FACILITY PLAN VIEW.

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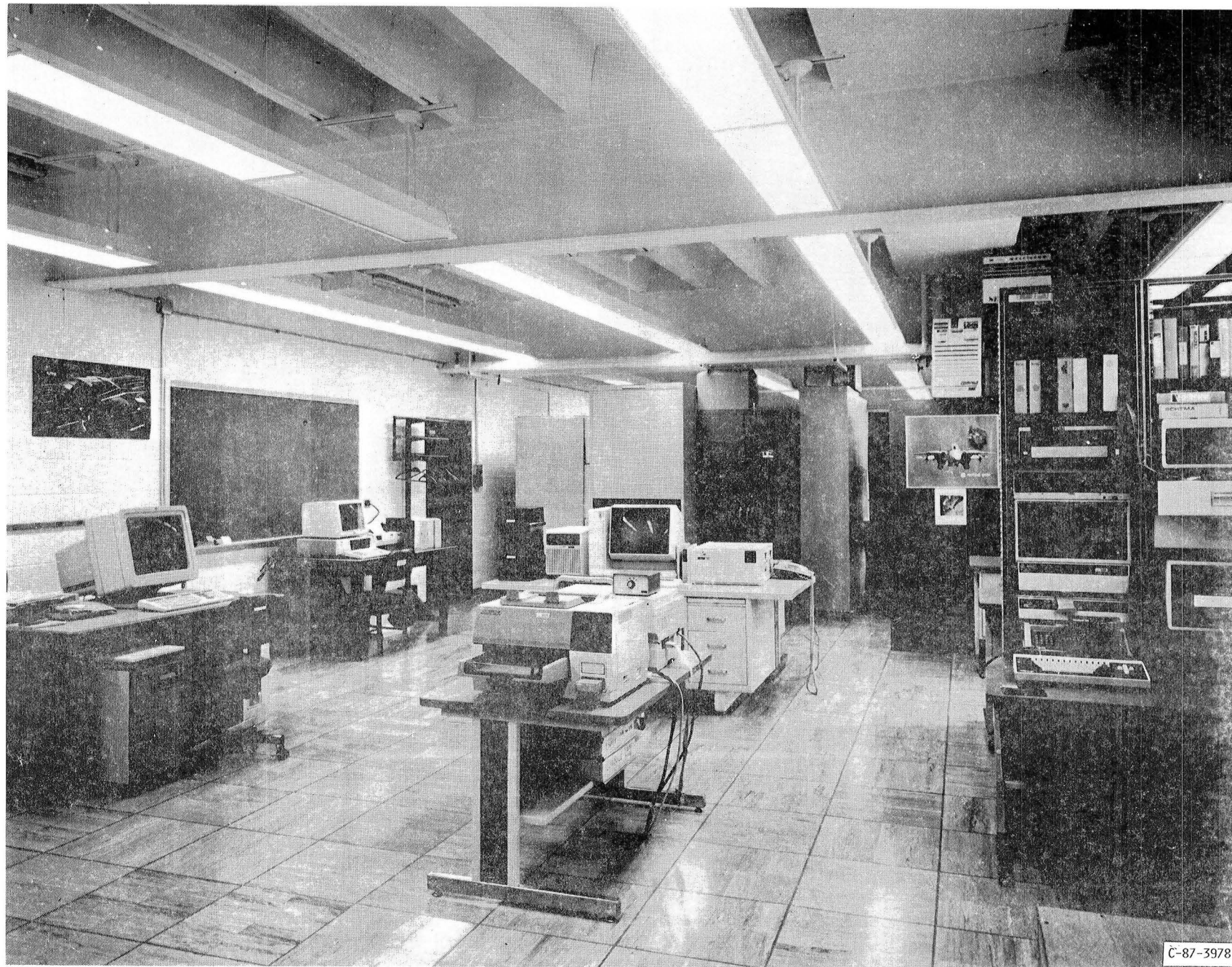


FIGURE 2.3.1. - EPS SIMULATION LAB.

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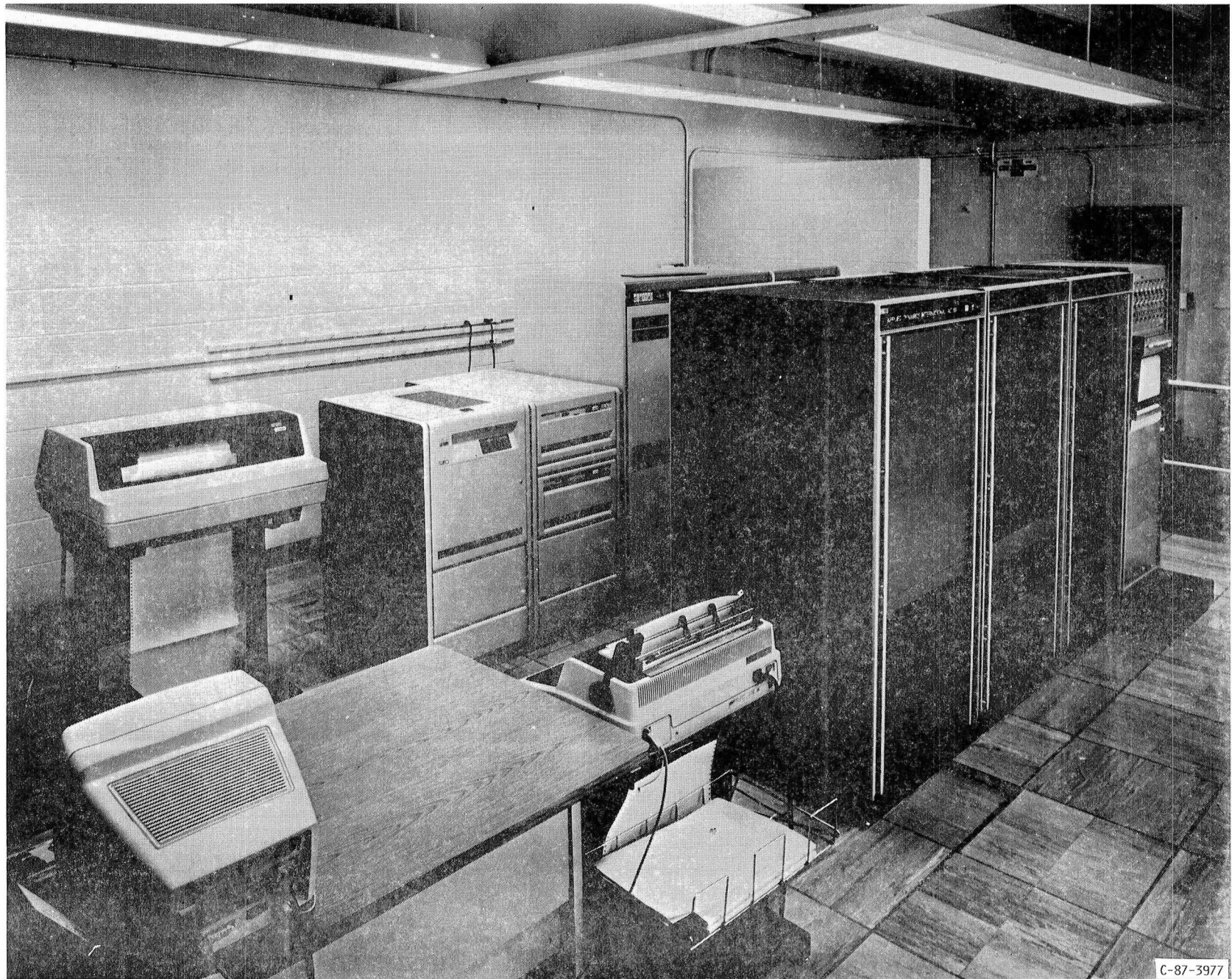


FIGURE 2.3.2. - EPS SIMULATION LAB.

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3.0 ADDITIONAL FACILITIES

The following facilities at LeRC have features which make them applicable to certain aspects of power system testing.

3.1 SPACE POWER TEST BED FACILITY - OPERATIONAL

The Space Power Test Bed Facility (SPTBF) is intended to provide a test bed for the PMAD development until the Power System Facility is completed. The facility, Fig. 3.1, consists of three buildings totaling 1,700 sq. ft. Air conditioning, ventilation, and cooling water are available. The building is divided into a battery storage room, a main test area, an interconnect/control room, and electronic shops.

The facility provides a 35kW (at the nominal array output voltage) solar array simulator, direct connection to the 40kW (peak) solar array field, and a 48kWh battery bank. DC and AC load banks, and the battery bank are available as loads. Data system capabilities are based on an Escort central data system.

SPTBF was developed to conduct 20kHz system testing, including source inverters, load converters, distribution system components and cabling, and computer controls. It is currently testing a 20kHz breadboard system. There are three pairs of source inverters, inverting the nominal 150VDC bus to a 440VRMS, 20kHz bus, 25kW maximum. There are three different load converters, a 5kW, 0-150V DC unit, a 25kW, 0-200V 3-phase AC unit with a frequency range of 13 to 3,333 Hz, and a 10kW, 150VDC bidirectional unit. The test bed also includes a 50m. transmission cable, fault switches, and computer control over the entire PMAD system.

3.2 SOLAR CONCENTRATOR OPTICAL TEST FACILITY - OPERATIONAL

The Solar Concentrator Optical Test Facility (SCOTF) equipment was originally developed in the late 1960's to test solar concentrators for the 15kW Solar Brayton Cycle Space Power System. The test equipment has been refurbished and relocated in a 1,200 sq. ft. room in the Electric Propulsion Research Building.

The facility contains a two axis platform which scans the surface of the concentrators. The scan is remotely controlled. The measurement of surface contour error and focal characteristics uses laser/video instrumentation. The primary function of this facility is the development of the measurement techniques and hardware and software to characterize solar concentrators. A schematic of the test fixture is shown in Fig. 3.2.

3.3 NICKEL-HYDROGEN CELL TEST BED - OPERATIONAL

The Nickel-Hydrogen Cell Test Bed (NHCTB) is dedicated to Ni-H₂ battery cycle testing. The NHCTB occupies an area of 400 sq. ft. and is located in the Space Power Research Laboratory. Air conditioning, ventilation, and the normal utilities are provided. The batteries are housed in a dry nitrogen purged enclosure to preclude hydrogen ignition or moisture condensation on the batteries.

The room is outfitted to test 42-65Ahr and 2-220Ahr cells, simultaneously. Twelve of the forty-two 65 Ahr stations provide charge and discharge currents capable of characterizing the battery limits, while the remaining stations provide normal operating charge/discharge rates. All the cells operate continuously and unattended, with independent charge/discharge cycles for each cell. Cell temperature and pressure, as well as the electrical parameters, are continuously recorded, and the cell is shut down automatically for out-of-tolerance conditions.

3.4 PV/SD/PMAD POWER TEST BED - OPERATIONAL

The PV/SD/PMAD Power Test Bed is a PMAD system test bed which features a rotating machine simulation of the solar dynamic source, as shown in Fig. 3.4. It occupies approximately 1,100 sq. ft. in two test cells and a control room in Building 5, the Engine Research Building (ERB).

The SD simulation is provided by a 1,200 Hz 15kW turbine-alternator originally designed for a space power system. The turbine is driven by service air and is computer controlled and can be programmed to simulate the SD system startup and shutdown. The PV simulation is provided by a 75kW electronic Solar Array Simulator which can supply 35kW at the nominal 160V array voltage. Load simulations are provided by a 20KVA 1,200Hz load bank, a 15kW resistive load bank, and a 32kW, DC to 20kHz, programmable load bank. Testing with actual motor loads is planned.

The facility uses a 20kHz PMAD system between the source and load simulations. The facility is under computer control, including the load banks and SD and PV simulators. An adjacent power electronics lab will supplement the testing of individual PMAD components.

3.5 ENVIRONMENTAL CHAMBERS - PARTIALLY OPERATIONAL

The Electric Power Laboratory (EPL), Building 301, contains two large environmental chambers suitable for Space Station development work. The building contains two high bay areas with overhead cranes, a 300 sq. ft. class 100,000 clean room, and the usual utilities in addition to a 55,000 gallon LN₂ storage for the cold walls and diffusion pumps. The chambers, Fig. 3.5, have an air conditioned control room and connection to the LeRC central data system.

Tank 5 is a 15 ft. diameter by 63 ft. long tank capable of 5×10^{-7} torr, and pumping speeds in excess of 4×10^6 liters/second. This tank is currently operational.

Tank 6 is currently out of service pending a proposed 1989 CoF refurbishment. It is a 25 ft. diameter by 70 ft. long chamber with the same base pressure as Tank 5, and a pumping speed of 2.5×10^5 liters/second. It contains a LN₂ cooled radiation heat sink. Operations in this facility will resume in 1991, contingent upon the proposed refurbishment. The CoF will primarily provide for decontamination, modernization of the controls and instrumentation, and refurbishment of some mechanical systems.

The B-2 Facility at the Plum Brook station, Sandusky, Ohio was originally developed to conduct upper stage vehicle firing tests under thermal vacuum conditions. The chamber is 55 feet high and 33 feet in diameter and contains a LN₂ cold wall and a solar simulator. Main access to the chamber is through the 27 foot diameter top lid, serviced by a 20 ton traveling bridge crane. Vacuum capability is 1×10^{-7} torr. The facility contains LN₂, LH₂ and LOX systems and standard electrical service, cooling tower water and service air. The main building has four floors of approximately 5000 sq. ft. each. Control and monitoring is done from a remote building.

The B-2 Facility was placed in standby in 1974, but was partially reactivated (without the cold wall and full remote control and monitoring) in 1987. The B-2 area is shown in Fig. 3.5.2.

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FIGURE 3.1. - SPACE POWER TEST BED FACILITY.

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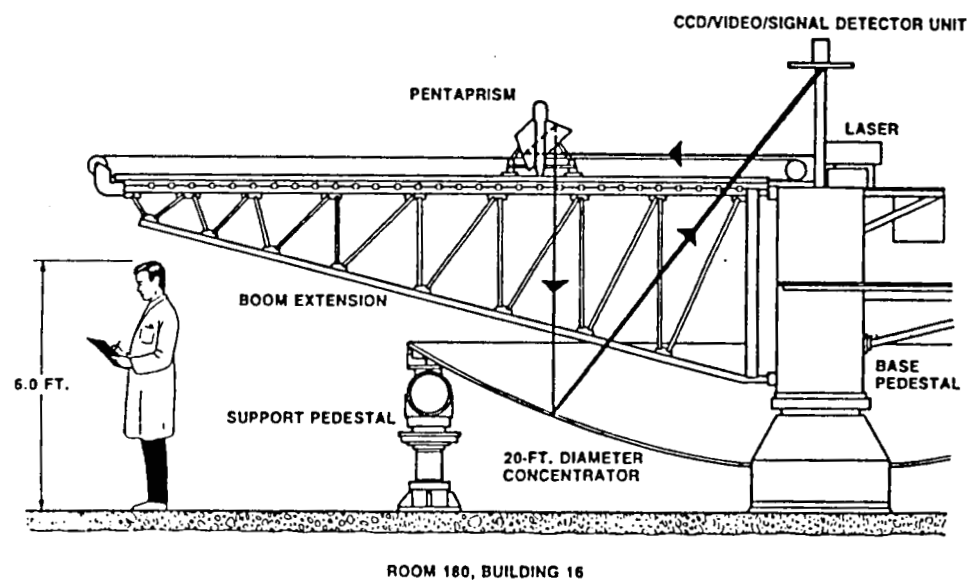
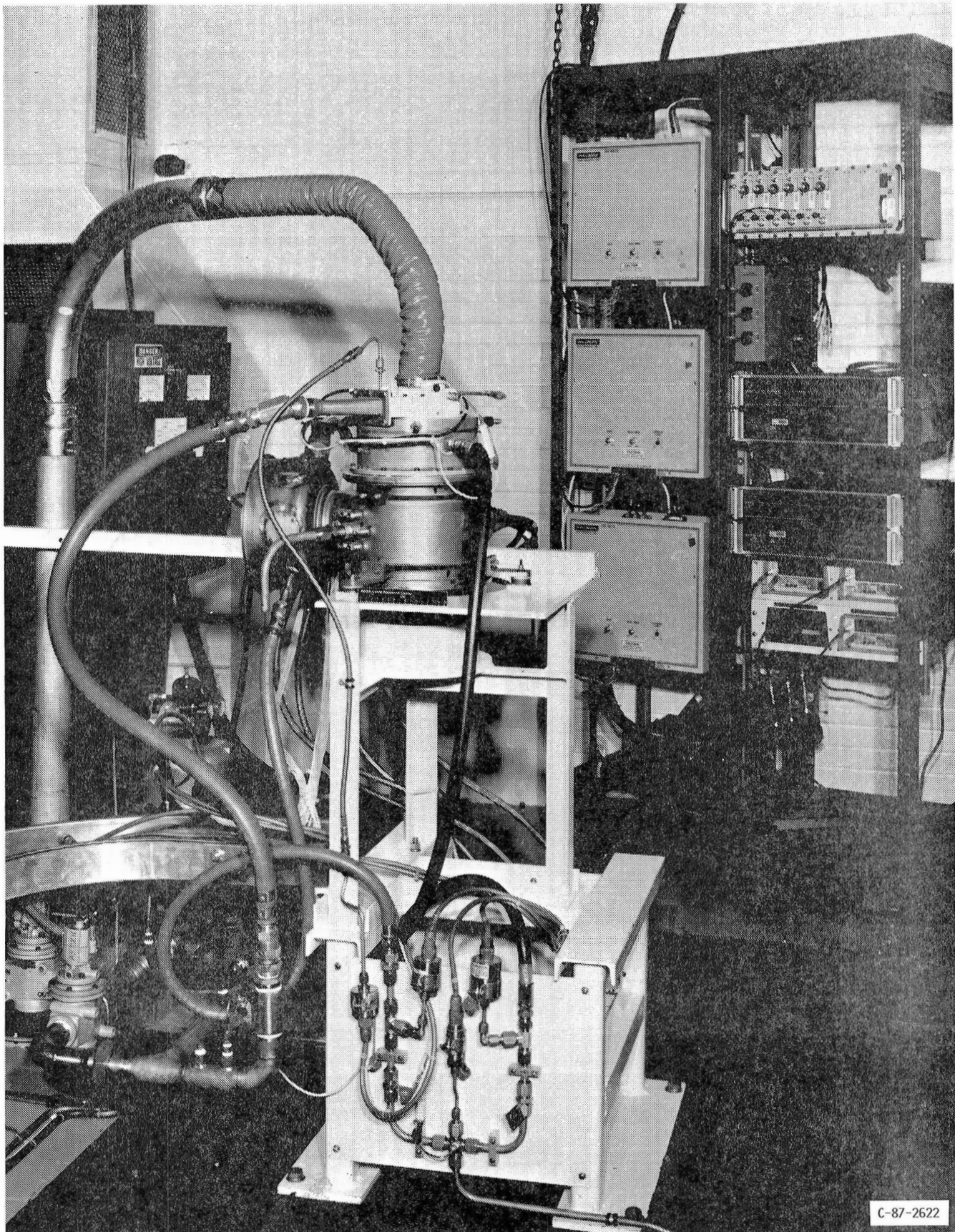


FIGURE 3.2. - SOLAR DYNAMIC CONCENTRATOR OPTICAL TEST FACILITY.

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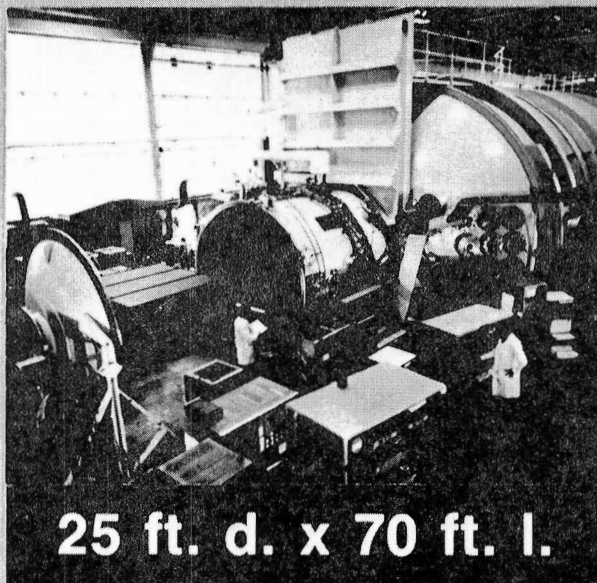
FIGURE 3.4. - SOLAR DYNAMIC SIMULATION.

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Lewis Research Center

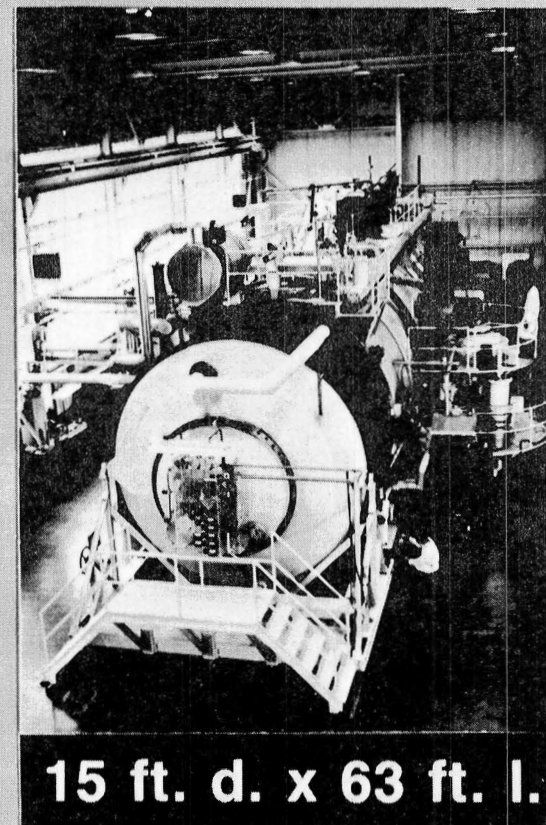
NASA

SPACE ENVIRONMENTAL CHAMBERS



25 ft. d. x 70 ft. l.

VACUUM
FACILITIES



15 ft. d. x 63 ft. l.

ENVIRONMENT

ALTITUDE: 300 KILOMETERS
(186 MILES)

MINIMUM TEMP. - 300° F

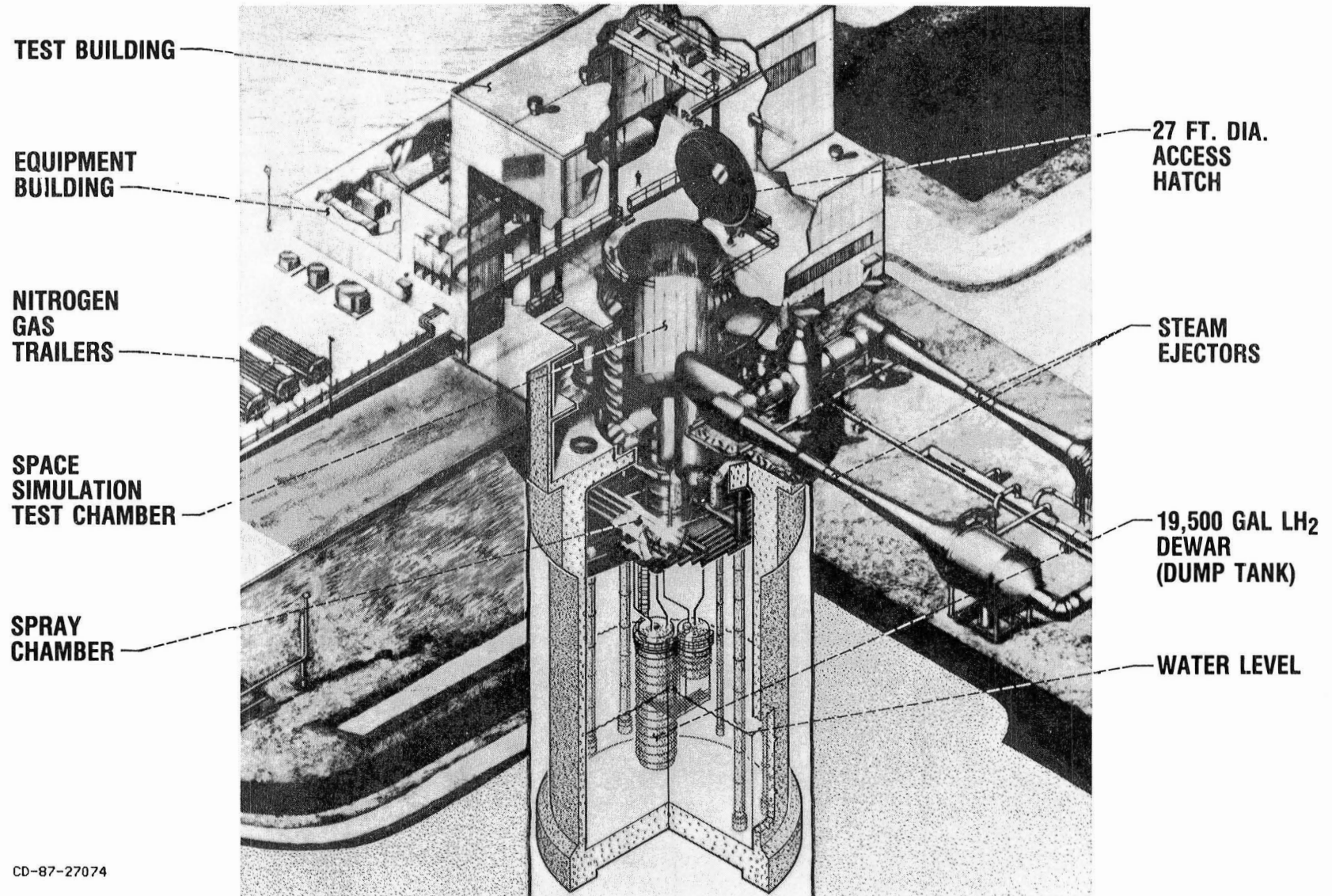
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FIGURE 3.5.1. - SPACE ENVIRONMENTAL CHAMBERS.

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SPACECRAFT PROPULSION TEST FACILITY (B-2)



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FIGURE 3.5.2. - PLUM BROOK B-2 FACILITY.

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4.0 RESPONSIBILITIES

Use of the LeRC facilities will be a cooperative venture between the Contractor and LeRC. In addition cooperative ventures may also result between LeRC and other Space Station work packages. This section establishes a baseline approach for the responsibilities of the Contractor and the Government.

The use of LeRC facilities is subject to the negotiations of specific permit agreements establishing conditions and defining the responsibilities of the Contractor and NASA. The negotiated agreements shall include a description of the tests to be performed, test plan requirements, scheduling, rights to data, and provisions for termination.

It is to be emphasized that the test bed utilization will require close coordination between the Contractor, the NASA Work Package Manager and the NASA facility and operations personnel. All tests performed in the NASA facilities will be conducted in accordance with the negotiated agreements and detailed test plans developed by the Contractor, the NASA Work Package Manager, and the NASA facilities and operations personnel.

The basic split in responsibilities is the line between the experimental hardware and its operation as compared to the test facility and its operations. The responsibilities of the organizations are as follows:

For WP-04, the Contractor shall provide the following items:

1. A Test Requirements Document as defined in the RFP section F-1, data requirement E-04.
2. A Test Plan as defined in the RFP section F-1, data requirement E-05. The test plan must prescribe a formal procedure to assure the completeness and validity of the test sequence.
3. The test hardware, software, and special instrumentation and data systems, including documentation sufficient to allow installation into the facility and integration with the facility systems.
4. Primary responsibility for the assembly, disassembly, installation, and removal of test hardware, and integration of the test hardware with the facility.
5. Checkout of the test hardware, and determination that the equipment is ready for formal testing.
6. Operations of the test hardware during the formal testing.
7. Analysis and reporting of the data.

8. Other services as required to assure the success of the test program.

For WP-04, the Government will provide:

1. Scheduling of the facility within the constraints of the test requirements and other facility utilization.
2. Modifications of the facility needed to fulfill the requirements, including the design, fabrication, and installation of the modifications.
3. Interconnection to facility service, controls, and central data systems, and support of contractor installation and removal of the hardware to the extent agreed to with the Contractor.
4. Checkout of the facility.

SPACE STATION SYSTEMS DIRECTORATE

ELECTRIC POWER SYSTEM

TEST FACILITIES

LIST OF CHANGES

APRIL 28, 1988

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16. Abstract NASA Lewis Research Center facilities have been developed to support testing of the Space Station Electric Power System. The capabilities and plans for these facilities are described. The three facilities which are required in the Phase C/D testing, the Power Systems Facility, the Space Power Facility, and the EPS Simulation Lab, are described in detail. The document also discusses the responsibilities of NASA Lewis and outside groups in conducting tests.					
17. Key Words (Suggested by Author(s)) Test Facility; Space Station; Power Systems Facility (PSF); Space Power Facility (SPF); EPS Simulation Lab; NASA Lewis Research Center Environment Chamber; Electrical Power System; Space Power Test Bed Facility (SPTBF); Solar Concentrator Optical Test Facility (SCOTF); Nickel-Hydrogen Cell Test Bed (NHCTB); Electric Power Laboratory (EPL)				18. Distribution Statement Unclassified - Unlimited Subject Category 14	
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